7. THE EAST ASIAN WINTER MONSOON

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The midlatitude component of the East Asian winter monsoon (EAWM) is characterized by the cold-core Siberian-Mongolian High (SMH) at the surface whose variability affects all scales of the extratropical circulations. The SMH has been weakening in recent decades, which appears to correlate with the negative phase of NAO/AO due to increased warm air advection over the Eurasian continent and the resultant reduction in snow cover. However, it is not clear that this recent decrease in the EAWM intensity is unique in the most recent 400 years. Periodical cold air outbreaks that cause high-impact weather are associated with the intraseasonal and synoptic variation of the SMH, and they often continue as cold monsoonal surges into the tropics and affect the tropical component of the EAWM. There is some evidence that intraseasonal variability has decreased in 1990s although extreme weather events in the past few years counter this trend. An important mechanism for the intraseasonal and higher frequency enhancement of the SMH comes from upper level blocking ridges over the Atlantic and the Pacific. The Atlantic blocking triggers a Rossby wave train that has a downstream effect of enhancing the SMH. The Pacific blocking forces the SMH through slow retrogression of the blocking center.

1. Introduction

The planetary scale circulations of the Asian winter monsoon has a much larger meridional span than that of the Asian summer monsoon, with a strong interaction between its equatorial heat source around the Maritime Continent – northern Australia and the baroclinic systems in the middle and higher latitudes. The extratropical circulations that are characterized by low-level anticyclonic circulations around the cold-core Siberian-Mongolian High (SMH) is further influenced remotely by motion systems at large distances, particularly upper level circulations in the Atlantic and Europe upstream from extratropical Asia. The movement of the

surface SMH can trigger cold air outbreaks that affect China, Korea and Japan and often reach deep into the tropics within a few days. The resultant surge of the northeasterly winds over the South China Sea, described as cold surges, monsoon (wind) surges, or pressure surges, can lead to heavy convection and severe weather in the Southeast Asia and the Maritime Continent region. The strongest circulations are situated over East Asia, making the East Asian winter monsoon (EAWM) the dominate component of the Asian winter monsoon and the most energetic planetary scale circulation system of the global atmosphere. Imbedded in the EAWM are severe monsoon weather disturbances such as snow storms, cold spells, torrential rainfall and floods, which have been the leading causes of weather related damages and disasters during winter over the huge area of East Asia. Strong interannual and month-to-month variations in the severe winter monsoon weather activities have been particularly difficult to forecast. In this paper we will review recent research on the variations of EAWM at various time scales, including month-long record-breaking extreme weather events in three of the last six winters of the most recent decade.

2. Interannual and Longer Term Variations

Several EAWM indexes based on winds, wind shears, and pressure gradients have been proposed to represent the strength of the EAWM. Most of these show a relationship with El Niño-Southern Oscillation (ENSO) due to atmosphere-ocean interactions such that the EAWM is often weak during warm years. (e.g., Chan and Li 2004; Chang *et al.* 2004). Some of the studies also found a relationship with the Arctic Oscillation (AO)/North Atlantic Oscillation (NAO) on the decadal time scale (e.g., Gong *et al.* 2001; Jhun and Lee 2004; Wu *et al.* 2006, see Fig. 1). Jhun and Lee interpreted this correlation as a result of influence from the snow cover over Siberia and northeastern Asia in autumn. A lack of autumn snow cover during AO positive phase would lead to a delay and weakening of the buildup of cold air over the SMH region and weaker cold advection from high latitudes. A similar multi-decadal relationship that relates the weakening of the SMH and the EAWM with the warm phase of Atlantic Multidecadal Oscillation was reported by Li and Bates (2007). A dynamical perspective of the weakening of the EAWM was offered by Wang *et al.* (2009) who proposed that the weakening is related to an interdecadal variation of the quasi-stationary planetary waves.

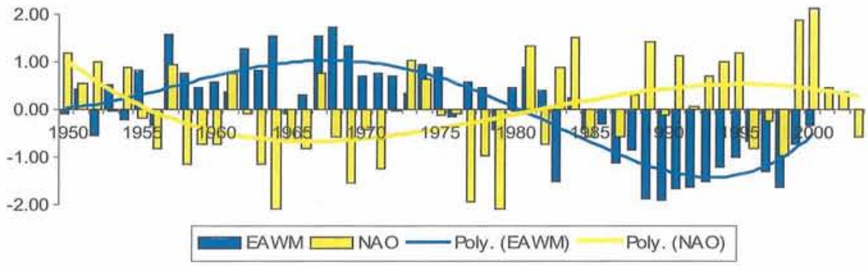

Figure 1. Time series of EAWM (blue bars) and NAO (yellow bars) indices. The blue and yellow curves are the fourth order polynomial fit of EAWM and NAO time series, which represent the decadal variations. EAWM index is defined as SLP averaged over 40°N-60°N, 70°E-120°E. (Chang *et al.* 2006, adapted from Gong *et al.* 2001, data courtesy of Qiyuan Guo)

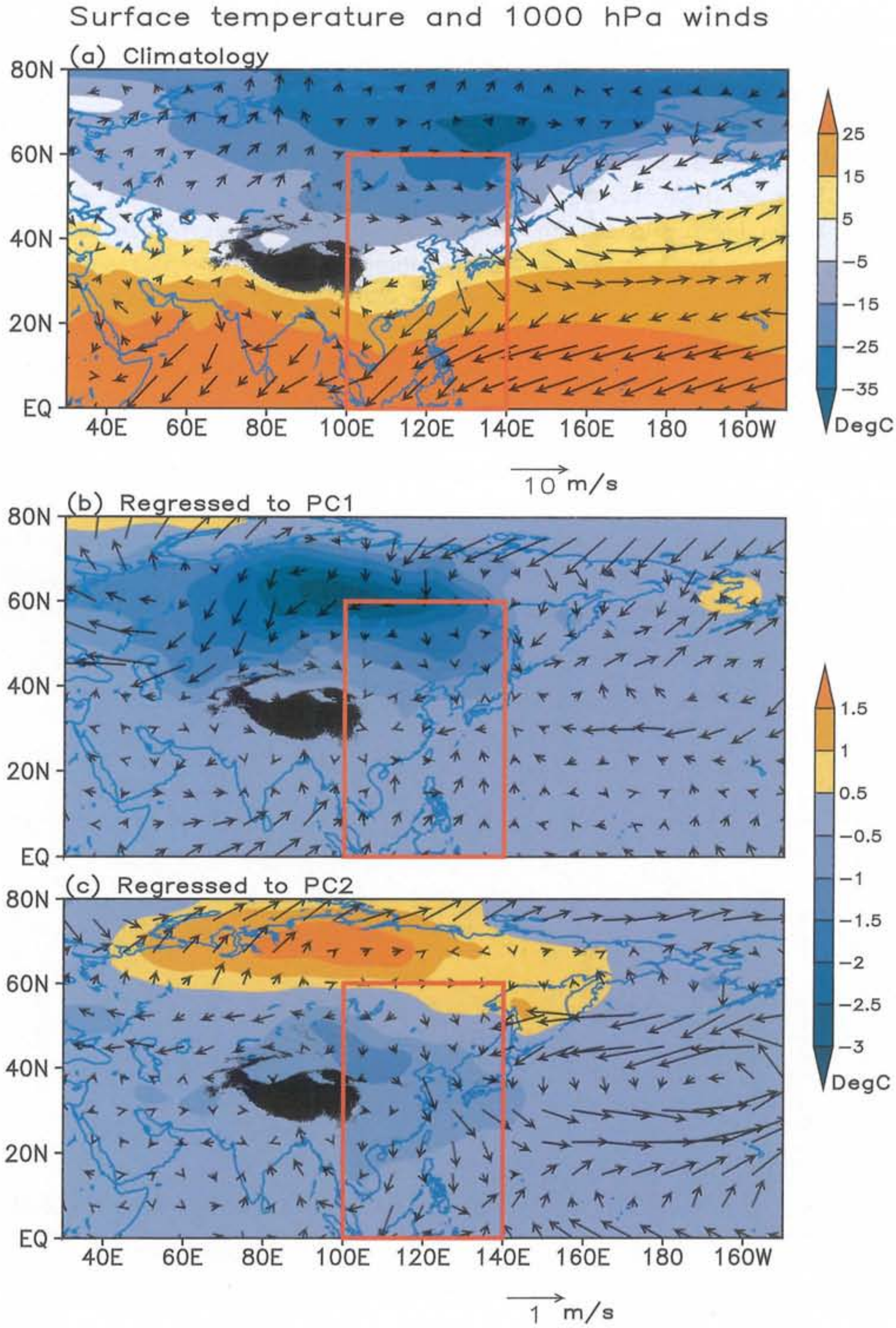

Figure 2. Sea-level pressure (contour in units of hPa), 2-m air temperature (Ts; color shadings, °C), and surface winds (vectors) for (a) climatological winter (DJF) mean, and anomalies regressed with reference to (b) the northern mode (PC1), and (c) the southern mode (PC2). The rectangular area is the EAWM region where the temperature field was used for the principal component analysis. (Wang *et al.* 2010)

Recently Wang *et al.* (2009) identified two major temperature modes during winter over East Asia based on 2 m air temperature, with their largest amplitudes north and south of 40°N, respectively (Fig. 2). Although derived from analysis of the East Asian temperature, both modes show temperature variability beyond East Asia and cover the entire Asia. The northern mode, characterized by a westward shift of the East Asian major trough and intensification of the Central Siberian High over 55°N-70°N, 90°E-120°E, represents a cold winter in the northern East Asia due to cold air intrusion from northeastern Siberia. This mode is preceded by excessive autumn snow covers over southern Siberia and does not appear to correlate with ENSO. The southern mode features a deepening East Asian trough and strengthening Mongolian High over 40°N-55°N, 90°E-120°E. This mode represents a cold winter and enhanced monsoon circulation south of 40°N due to cold air intrusion from Mongolia. The wind field associated with the southern mode inside the EAWM domain resembles the EAWM circulation defined by wind and pressure data in previous studies. It is preceded by the development of La Niña episodes and reduced autumn snow cover over northeast Siberia. The interannual variations of the two temperature modes exhibit remarkably different spatial-temporal structures and origins, but on the interdecadal time scale their structures are somewhat similar with an abrupt regime transition in the mid-1980s and are preceded by comparable autumn sea surface temperature anomalies over the North Atlantic and tropical Indian Ocean.

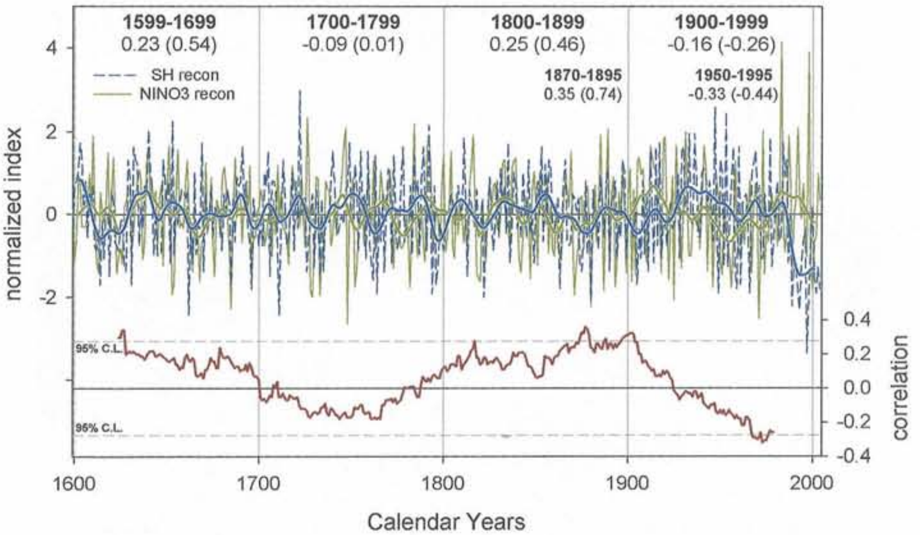

Figure 3. Time series of the normalized Dec-Feb Siberian High (SH) Index and Nino-3 SSTs reconstructions for different subperiods. Correlations for subintervals identified by Robock *et al.* (2003) are also indicated. Correlation between the instrumental EAWMI and Niño-3.4 SSTs is -0.25, not significant over 1958-2000 (Jhun and Lee 2004). Lower panel shows 51-year running correlations (D'Arrigo *et al.* 2005).

There is some evidence that in the recent decades the EAWM has undergone a weakening that may be related to the global warming. A dramatic declining trend of the Siberian High between 1978 and 2001 was identified by Panagiotopoulos *et al.* (2005), who reported that a

Siberian High Index reached the lowest values since 1871. D'Arrigo *et al.* (2005a) suggested that this decline of the Siberian High since the late 1970s may be related to Eurasian warming and reconstructed tree-ring data suggest this decline is the most striking feature of sea-level pressure over the past 400 years. On the other hand, in a separate paper D'Arrigo *et al.* (2005b) found that the pressure gradient between the Siberian High and the Aleutian Low showed similar weakening signals in the late 17th and 19th centuries. Therefore, the recent weakening of EAWM may not be unprecedented. They also showed that a correlation between the Siberian High and a tree-ring reconstruction of the ENSO signal varies with time over the past 400 years (Fig. 3). For example, the recently observed negative correlation between ENSO and EAWM is the opposite of the correlation in the 19th century. Thus, in a longer-term context, the winter monsoon – ENSO relationship can be quite different from the perspectives obtained by analyzing only the 20th century data.

3. Intraseasonal and Shorter Term Variations and Cold Air Outbreaks

Takaya and Nakamura (2005a) elucidated the mechanism of intraseasonal amplification of the SMH from the formation of upper level blockings. Their potential vorticity (*PV*) inversion analysis indicates an interaction between an equivalent barotropic Rossby wave train with maximum amplitudes at the tropopause and preexisting surface cold anomalies that enhance the baroclinicity. The wave train becomes more baroclinic as it propagates into central Siberia. The upper-level *PV* anomalies associated with the blocking enhance the surface northeasterlies and strengthens the preexisting cold anomalies. The alignment of surface and mid-tropospheric anomalies enhances the surface northerlies downstream and brings cold air advection that results in further eastward extension of the cold anomalies. The enhanced surface cold anomalies, in turn, can induce anomalous anticyclonic circulation throughout the troposphere to maintain the upper-level blocking ridge and reinforce the cyclonic anomalies downstream. The upper blocking ridge and surface cold anomalies act to “lock” one another through the interaction, so as to keep their phase relation appropriate for their mutual reinforcement. (Figs. 4 and 5).

Since the Atlantic-origin blocking exerts its effect through a quasi-stationary Rossby wave packet propagating eastward, Takaya and Nakamura (2005b) reasoned that it is difficult for such a wave packet to cross the weak westerlies in the East Asian major trough, therefore northeastern Siberia can only be influenced by the Pacific variability. In contrast to the wave train propagating across the Eurasian continent under modest feedback forcing from transient eddies, the Pacific-origin blocking is associated with the westward development of anticyclone anomalies from the North Pacific under stronger transient eddy feedback forcing along the Pacific storm track. Thus, the Pacific-origin blocking effect is characterized by no signature of incoming wave packet and by slow retrogression of the blocking center (Fig. 6).

The relationship between AO and high frequency variability may be regionally dependent. Gong and Drange (2005) showed that while northern Europe had much stronger variability in high AO years, Siberia had it in low AO years. Even within the EAWM region there are local variations. Isobe and Beardsley’s (2007) analysis of 19 winters found that the occurrence of

cold air outbreaks over the northern Japan Sea exhibits a clear interannual variation and a significant positive correlation with AO. This relationship is through weather disturbances that originate in the East China Sea, where the SST changes depend strongly on the AO phase. During the positive AO phase the East China Sea is warm, the low pressure disturbances tend to develop and intensify, leading to stronger cold-air outbreaks and increased sea surface cooling over the northern Japan Sea.

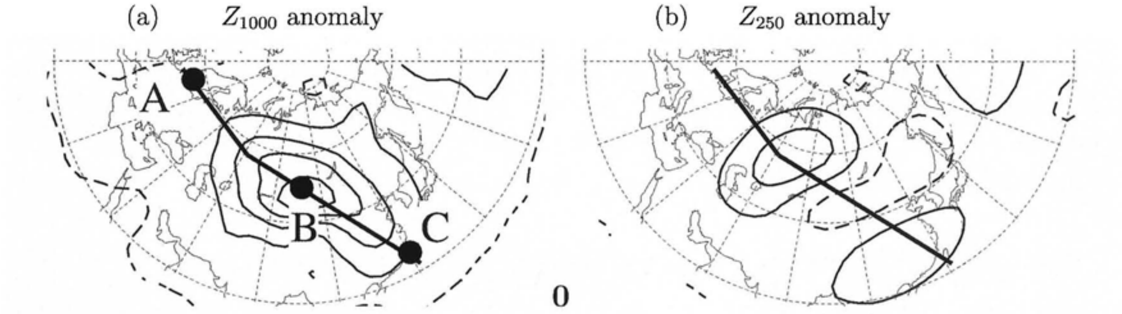

Figure 4. The line along which vertical sections in Fig. 5 are taken, superimposed on the composite (a) Z_{1000} (interval 40 m from 20 m) and (b) Z_{250} (100 m from 50 m) anomalies for the peak times of the 20 strongest events of the surface Siberian High around a target grid point (47°N, 90°E). The Z_{1000} and Z_{250} anomalies are both normalized by sin(45°N)/sin(lat), and negative values are indicated with dashed lines. Labels A, B, and C correspond to those in Fig. 5. (Takaya and Nakamura 2005a)

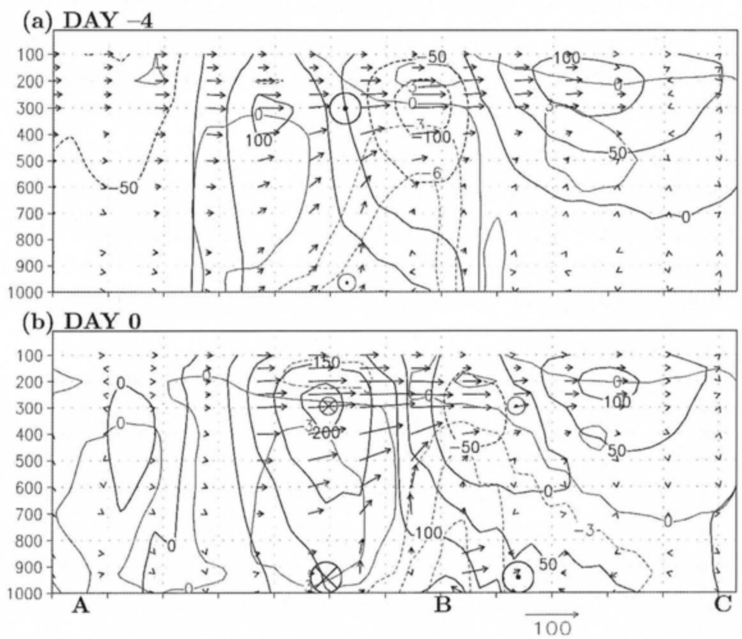

Figure 5. Vertical cross sections of a wave activity flux along the line in Fig. 4, based on the composite time evolution for (a) 4 days before the peak time, and (b) the peak time, of the 20 strongest events of the surface Siberian High at point (47°N, 90°E). (unit: $m^2\ s^{-2}$ for horizontal component and 10^{-1} Pa m s^{-2} for vertical component). Contour are low-pass-filtered geopotential height anomalies (interval 50 m) normalized by sin(45°N)/sin(lat) and temperature anomalies (light contours every 3 K). Anomalous wind velocity induced by upper-tropospheric *PV* anomalies and surface temperature anomalies are also indicated in (a) and (b), respectively. (Takaya and Nakamura 2005a)

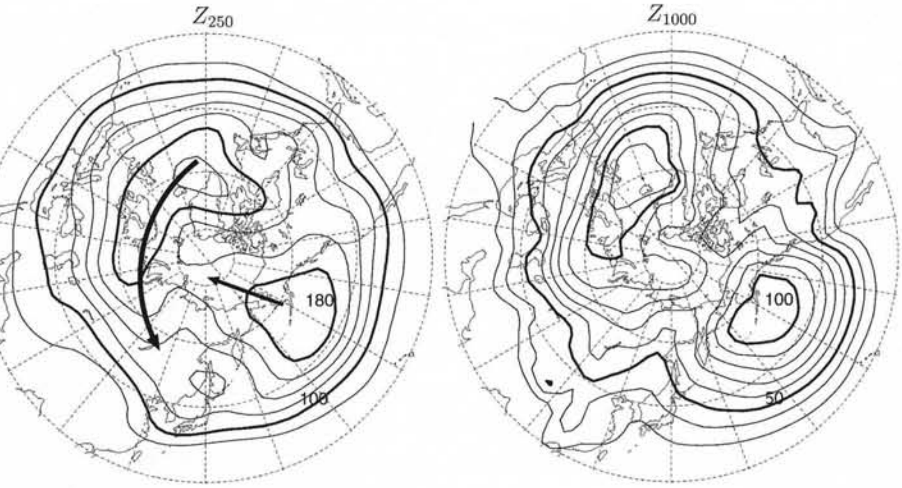

Figure 6. Local standard deviation of low-pass-filtered anomalies in (left) Z_{250} and (right) Z_{1000} for winter. Contour intervals are shown every 20 m for Z_{250} (heavy lines for 100 and 180 m), and every 10 m for Z_{1000} (heavy lines for 50 and 100 m). In the left panel, an arrow drawn from the North Atlantic into Eurasia indicates a typical waveguide for stationary Rossby wave trains (Blackmon *et al.* 1984), and another arrow drawn over the Bering Straight indicates a typical direction of inward breaking of the polar vortex, as in Fig. 4. (Takaya and Nakamura 2005b)

On the other hand, Gong and Ho (2004) analyzed the winter temperatures at 155 Chinese and Korean stations during 1954-2000 and found that the intraseasonal variance generally decreases, and that this trend is particularly clear over northeastern China. In addition, cold extremes became more frequent and warm extremes less frequent (Fig. 7). Intraseasonal variance of the SMH and AO are correlated with the temperature variance, which is affected by the seasonal mean AO through its modulation of the SMH. The mean AO has intensified during the last two decades while the frequency of intense SMH has decreased and the intraseasonal variance of the SMH has decreased. This view is consistent with observational studies such as those by Jeong and Ho (2005) and Hong *et al.* (2008), who reported less frequent cold surges during the positive AO/NAO phase.

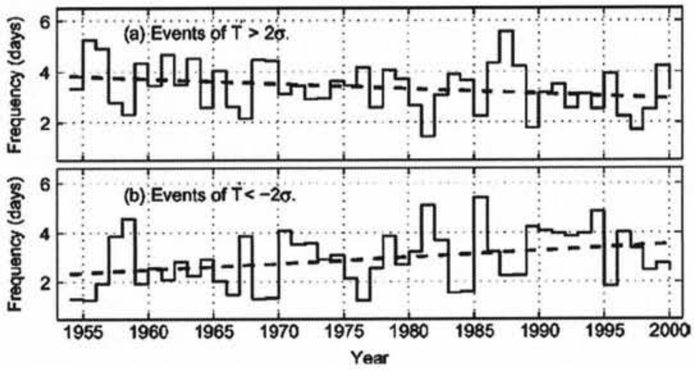

Figure 7. Frequencies of extremely high (upper panel) and low (lower panel) daily temperature anomalies in the northeastern section of the analysis domain (north of 40°N and east of 110°E). (Gong and Ho 2004)

4. Recent Extreme Events: 2005 Late Winter Cold Surges, 2008 South China Snow Storms, and 2010 Persistent Cold Spells

Starting from the middle of the first decade of the 21st century, the EAWM has been more active than normal. Extremely cold periods lasting one month or more affected various parts of the region three times in a span of six seasons.

The first period was in late winter 2005, when the highest frequency of late winter cold surges in East and Southeast Asia over 50 years was recorded, with three strong successive surges occurring within a span of 30 days from mid-February to mid-March. These events also coincided with the first break of 18 consecutive warm winters over China. The strong pulsation of the surface SMH that triggered these surges was found by Lu and Chang (2009) to result from the confluence of several events. To the east, strong Pacific blocking with three pulses of westward extension intensified the stationary East Asian major trough to create favorable condition for cold surges. To the west, the dominance of Atlantic blocking provided the source of a succession of Rossby wave activity fluxes for the downstream development. An upper level Central Asian anticyclone (Figs. 8, 9) that is often associated with a stronger SMH was anomalously strong and provided additional forcing.

Lu and Chang (2009) found that the strength of this Central Asian anticyclone is correlated with AO and NAO only when SMH is weak (warm winters). During strong SMH seasons (cold winters) the correlation vanishes. But during late winter 2005 the Central Asian anticyclone was strengthened by Atlantic blocking through both the downstream wave activities and a circulation change that affected the Atlantic and West Asian jets. As a result, late winter 2005 stands out as a record-breaking season in the Asian winter monsoon.

The second cold period was during January and February 2008, a La Niña period, when China experienced the worst winter in 50 years. Unusually frequent and persistent snowstorms caused wet and cold weather and severe icing conditions over central–southern China. Wen *et al.* (2009) found these conditions closely linked to the change in the Middle East jet stream (MEJS), which may be viewed as the western branch of the West Asian jet. The MEJS is usually strong when the subtropical western Pacific High is farther north than normal in La Niña winters. The cold conditions extended to lower latitudes producing extreme cold anomaly over Southeast Asia during February 2008. Hong and Li (2009) observed that a combined effect of the ISO and La Niña maintained a prolonged positive heating anomaly over the Maritime Continent through the anomalous Walker circulation. The anomaly produced a persistent northerly anomaly reaching Southeast Asia. Meanwhile, the extensive region from the Bay of Bengal to tropical west Pacific was occupied by strong and persistent southeasterlies that transported a large amount of moisture to the central-Southern China to form snow and freezing rains. This type of interaction between dry and cold air from north and warm and moist air from south in the Yangtze-Huaihe River basins and South China is very rare during winter (Ding *et al.* 2008).

The third cold period occurred in the middle of the 2009/2010 winter, when most of the Northern Hemisphere midlatitude regions were anomalously cold and record breaking low temperatures were observed over northern China, Japan and Korea. At the time of this review,

no research has been formerly published discussing this global severe cold season, but strong evidence points to the influence of an extremely negative AO. Since the previous two decades AO was mostly positive, it will be of interest to see if this signifies a decadal phase change which may mean more active (cold) EAWM in the second decade of the 21st century.

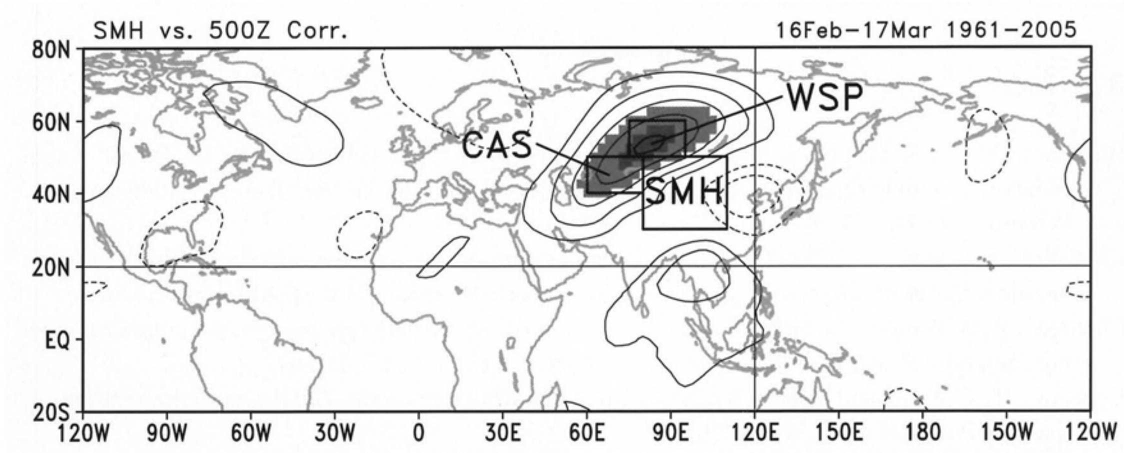

Figure 8. The late winter correlation of SMH and 500-hPa geopotential height during 16 Feb - 17 Mar from 45 years data (1961-2005). The correlation significant at 0.05 is shaded. (Lu and Chang 2009)

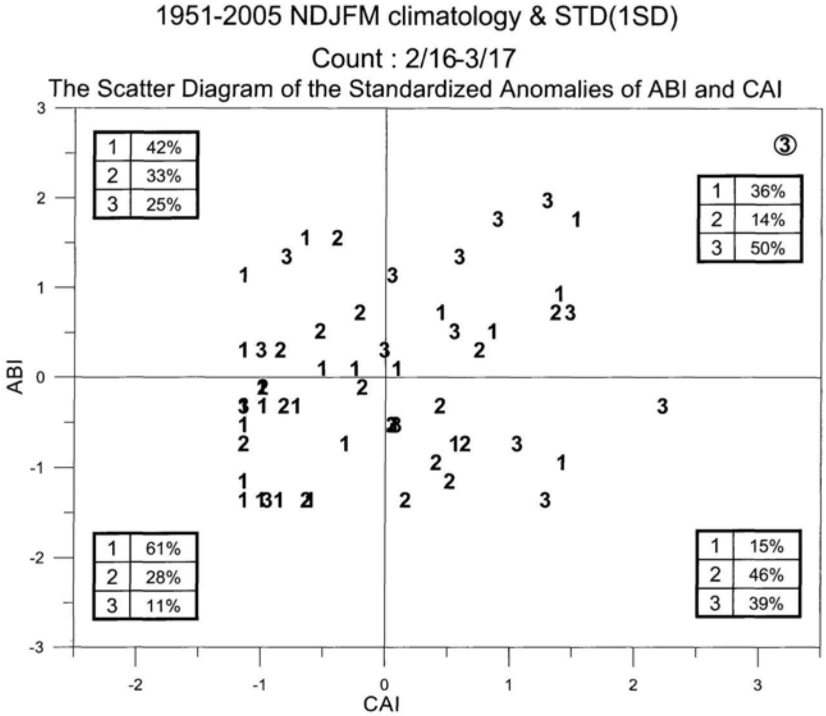

Figure 9. The scatter diagram of the SMH categories with respect to Central Asian Anticyclone and Atlantic Blocking indexes. The circle marks 2005. (Lu and Chang 2009)

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